2D HYDRAULIC MODELING FOR BARBS DESIGN TO PROTECT RIVER BANKS, CASE STUDY: SETI RIVER ALONG THE POKHARA-BAGLUNG HIGHWAY, NEPAL

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Abstract— Hydraulics of any river is better understood using numerical modelling. This study is concerned to design barbs for protection of Seti river banks along Pokhara-Baglung highway using two-dimensional (2D) hydraulic modeling in ANSYS Fluent. Desk study was conducted by collecting river flow data for seven years from 2009 A.D. to 2015 A.D. The geometry of the river reach near the weir section was drawn manually in geometry design modeler in Workbench. Face meshing with element size of 0.5m was performed in meshing module of Workbench. The model inputs used were: the stream geometry, roughness coefficient of 0.5 in each case, flow velocity of 3 m/s. Simulations were performed to obtain the velocity magnitude contours and velocity streamlines for all cases along with an additional base case without any barbs structure. The average length to width ratio (L/B) and average Spacing to length ratio (S/L) of the structures used in this study are 0.25 and 1.5 respectively. The length of barbs was taken as 20m in each case and spacing in-between barbs was taken as 30m in cases with double barbs. The simulation results showed that, among all the cases considered, the one with double barbs at an angle of 90° to the upstream increases the flow velocity and confines the flow towards the centre of the river and thereby induces bank stability effectively.

Keywords—numerical modeling, barbs, face meshing, bank erosion, Simulations

I. INTRODUCTION

Importance of a highway is evident in a country where the major mode of transportation is roadway. River route in hill roads is common and its proximity to the river causes various problems depending upon the nature of river, its source, hydraulic properties and other aspects. The major problem in a river route is erosion of bed and banks of river that endangers the road alignment. Thus, it is obligatory to consider various river training techniques to protect the river banks to ensure safety of the route. One of the solutions can be the construction of barbs (quite similar to spurs, groins and submerged vanes) structure protruding into the flow at an angle upstream to the river bank for the purpose of deflecting the flow current away from the bank and minimize the erosion potential. Generally, the barbs structures are used to protect river banks for gentle meanders, or relatively straight banks. The primary function of barbs is to deflect the strong flow away from the critical zones and therefore, prevent erosion of the banks. The study area for this research work covers a portion of Pokhara-Baglung highway adjacent to the Seti River situated near the weir across SetiGandaki Irrigation Hydroelectric Project in Pokhara, Kaski district of Gandaki Province, Nepal.

Water flow current has the potential to cause bed scour, bank erosion and carry sediment load with water. Riverbank erosion is a cause of toe erosion of slopes inducing landslides and also posing risk to the adjacent infrastructures. Pokhara-Baglung highway is one of the important highways of Gandaki Province and connects Kaski to Parbat, Baglung and Myagdi, Mustang. In addition, it is undergoing widening and upgrading as a part of mid-hill highway.

The weir across the river is located at 83º58’22.7” latitude 28º15’02.29” longitude in Pokhara Metropolitan, Kaski.

Seti River flows in deep gorges through the central part of Pokhara Metropolitan and floods during the monsoon period in flanged part of the river, which causes bank erosion and inundation of settlements[6]. Seti river analysis in Pokhara Metropolitan city could be significant for the proper planning, development and protection of infrastructures within the vicinity of river. Survey data obtained from survey conducted by Water Resource and Irrigation Development Office, Kaski ensures that, slope of the river is less than 10% at the study section.

Figure 1 Study Area with flow direction (Source: Google Earth)

II. Methodology

A. Data Used

The data of gauge reading (depth of water at the crest of under sluice) for seven years from 2009 A.D. to 2015 A.D. of the Seti River is collected from Pokhara Water Conservancy and Irrigation Project, Pokhara, Nepal. From the respective stages and cross-sectional width of river upstream of the weir, cross sectional area of river flow discharge was calculated. The velocity was then calculated from the discharge and cross-sectional area.

TABLE I. DISCHARGE IN SETI GANDAKI RIVER AT TULSIGHAT AS PER ACTUAL GAUGE READING

S.N.	***Date of maximum yearly discharge***	***Head over the crest weir. H (m)***	***Maximum Discharge through weir (m^3/s)***
1	7 Oct 2009	1.50	251.3
2	30-31 July 2010	1.65	289.9
3	28 Jun 2011	1.50	251.3
4	5 May 2012	2.00	386.9
5	15-19 Jun 2013	1.25	191.1
6	18 Jul 2014	1.50	251.3
7	29 Jul 2015	1.35	214.5

The flow velocity (v) of 3m/s is used as input in inlet section while setting up for solution in ANSYS Fluent for obtaining solutions. The values of discharge (Q) through the weir and head over crest of the weir (H) shown in Table 1 is used for calculating the velocity of flow. During seven years' period from 2066 to 2072, maximum discharge through weir is 386.94 cumecs. The weir's width is 80 m and the height is 2 m. The velocity of flow is obtained to be 2.5 m/s using the cross-section information. For analysis purpose velocity (v) is taken as 3 m/s.

B. Barbs Design Guidelines

The general design guidelines of barbs (e.g., length, spacing) are available in many hydraulics textbooks. The design criteria of barbs vary with their purpose (e.g. bank erosion protection vs. navigation improvement) and are based on the prevailing flow regions in the vicinity of the barbs. The length of barbs depends upon the amount of flow needed to be redirected from the banks towards the main-core region and the maximum permissible flow depth and velocity in the region. Typical design specifications recommended that the barb length to stream width ratio (L/B) is less than 0.5 to prevent excessive constriction of waterway width causing excessive bed-scour in the main core region and backwater effects. The spacing between the barbs is governed by structure length and the typically recommended spacing to length ratio (S/L) is 0.75 to 2.0. In determining design criteria of barbs majority of studies to date have investigated the flow pattern around a single barb while in the field multiple barbs are often used to control bank erosion in a stream reach. A series of barb structures used in a stream reach can have large scale effects due to an increase in the total flow resistance of the reach creating backwater effects. The presence of barbs affects the water surface profile and the overall spatial distribution of the velocity in the main-core and the barb regions; therefore, it is essential to simulate the entire series of barbs to obtain a true picture of the large-scale effects of these structures on the hydrologic and morphologic characteristics of a stream.

C. Methodological Process

The methodological steps include a review of essential criteria for designing of barbs structure. Preliminary study of the respective site location was performed with the use of Google Earth. Brief review of design criteria for designing barbs structure was followed by description of the study site and collection of field data for model validation. Site visit was performed to assess the effectiveness of existing barbs structures. Simulation cases with various sets of barbs with different number of barbs and different arrangements were defined. Face meshing with element size of 0.5m was performed prior to 2D hydraulic modeling of river flow using Fluent. The velocity field near the river bank for different cases was analyzed and compared to select a best case of barbs to effectively minimize the bank erosion. The data of gauge reading was collected from Pokhara Water Conservancy and Irrigation Project, Pokhara, Nepal. The velocity to be used in the model simulation was calculated from the discharge and cross-sectional area.

Three location across the river are selected based on the vulnerability of flooding as depicted by the floodplain map of the study area for different return period [4]. With these proposed locations for barbs construction eight various cases are considered for the study. The cases comprise up of two arrangements i.e., double barbs (at spacing of 30m) and single barbs structure of two arrangements (at an angle of 30° to upstream and 90° to the bank) each of 20m length and 2 m. Table II shows various cross-sections where barbs are considered to protect the bank erosion.

The limitation of this study is in using 2D model given that the flow fields around such structures are strongly three dimensional.

TABLE II. VARIOUS CASES OF BARBS STRUCTURE

Case No.	*Description of Cases*	*Dimension of barbs (Width x Length)*	*Orientation of barbs*	*Spacing of barbs (Spacing/Length of structure=1.5)*
1	Single Barbs at A-A reach	20mx2m	at an angle 30˚ to upstream	
2	Double barbs at A-A reach	20mx2m	at an angle 30˚ to upstream	30 m
3	Single Barbs at A-A reach	20m x 2m	at an angle 90˚ to upstream	
4	Double barbs at A-A reach	20m x 2m	at an angle 90˚ to upstream	30 m
5	Single barbs at B-B and C-C reaches	20m x 2m	at an angle 30˚ to upstream	
6	Double barbs at B-B and C-C reaches	20m x 2m	at an angle 30˚ to upstream	30 m
7	Single barbs at B-B and C-C reaches	20m x 2m	at an angle 90˚ to upstream	
8	Double barbs at B-B and C-C reaches	20m x 2m	at an angle 90˚ to upstream	30 m

III. RESULTS AND CONCLUSION

A. Results

The two dimensional hydraulic model ANSYS Fluent was used to obtain the best alternative among different cases considered in terms of arrangement of barbs structure, alignment to the flow direction, number of barbs structure and spacing among the structures in case of double barbs structure. The model inputs are: the stream geometry, same roughness coefficient of 0.5 in each case, flow velocity of 3 m/s. The flow velocity considered taken by rounding up the actual maximum velocity observed in past years was used to evaluate the overall performance of the barbs in controlling bank erosion. In performing the numerical simulations, the model was run with and without the barbs present but our main concern is with different cases with barbs present. The flow condition in the case of no-barbs Figure 2 was used as reference for comparison and to evaluate the barbs effect on the river reach.

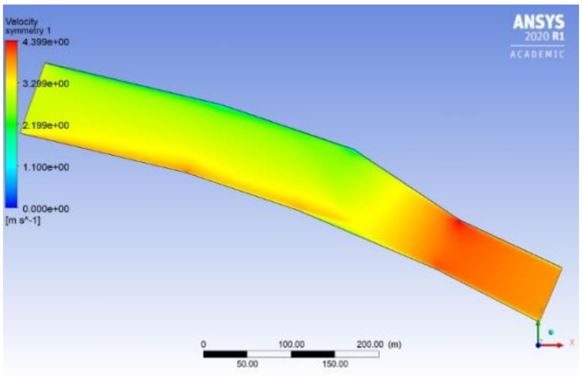

Figure 2 Base Case without barbs structure

The flow velocity magnitude and streamline of velocity in case with single barb (20mx2m, 30° upstream) at A-A as shown in Figure 3 and Figure 4 respectively shows that the velocity increases up to 6.5m/s maximum, downstream along the toe of the barbs structure and flow around the bank of the river around barbs structure substantially reduce to near zero. Compared with the base case the construction of barb structure at A-A the flow is confined towards the core of the river and flow velocity decreases at the bank of the river near the bank.

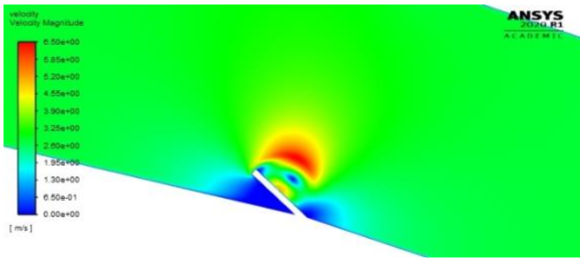

Figure 3 Single barb (20mx2m, 30° upstream)

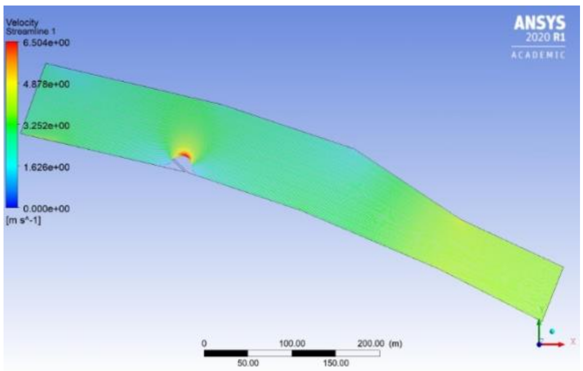

Figure 4 Streamline Single barb (20mx2m, 30° upstream)

In another case as shown in Figure 5 and Figure 6 with double barbs (20mx2m, at 30° upstream) at A-A with a space of 30m between them shows strange increase in velocity along the bank of the river downstream of second barb and obvious increase in flow velocity up to a maximum of 7.8 m/s downstream away from the toe of the barbs structure towards the core of the river.

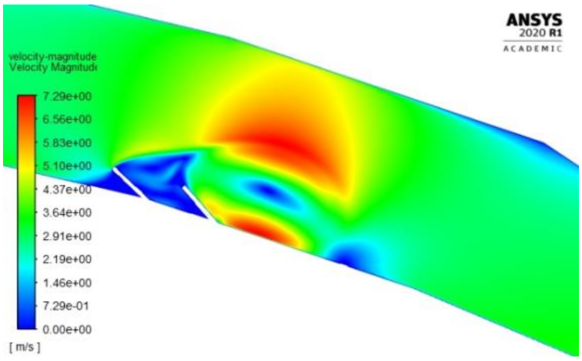

Figure 5 Double barbs (20mx2m, at 30°upstream)

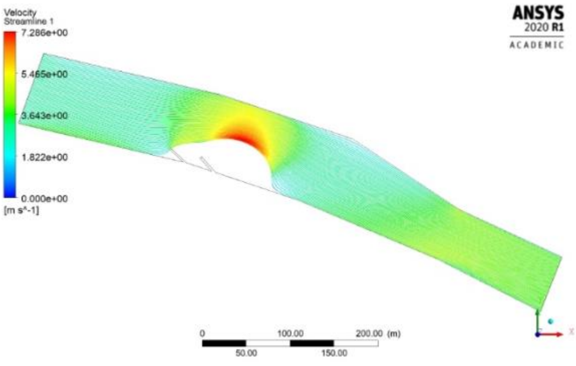

Figure 6 Streamline Double barbs (20mx2m, at 30°upstream)

The third case as shown in Figure 7 and Figure 8 with a single barb (20mx2m, 90° upstream) at A-A shows increase in flow velocity along the bank of the river and along the toe of barb (maximum velocity 8.4m/s), downstream of the barb structure.

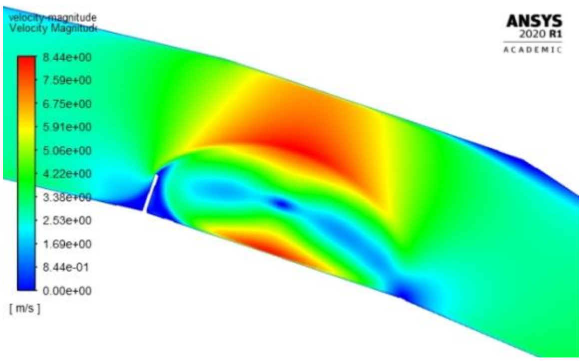

Figure 7 Single barb (20mx2m, 90° upstream)

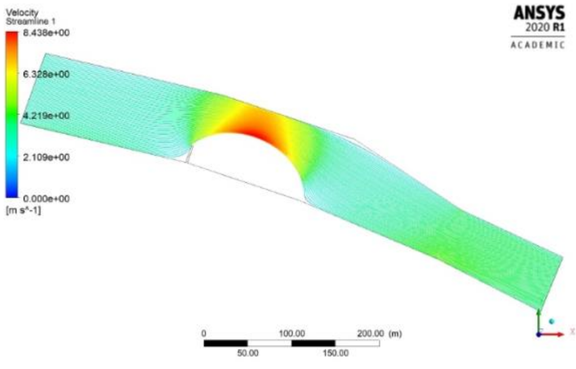

Figure 8 Streamline Single barb (20mx2m, 90° upstream)

The flow velocity magnitude and streamline of velocity in case with double barbs (20mx2m, 90° upstream) at spacing of 30m in between at A-A as shown in Figure 9 and Figure 10 respectively shows that the velocity increases up to 7.81m/s, downstream along the toe of the barbs structure and flow around the bank of the river around barbs structure substantially reduce to zero. The velocity magnitude shows that there is strange increase in flow velocity along the bank of the river downstream of the barbs arrangement. Compared with the base case the construction of barb structure at A-A the flow is confined towards the core of the river and flow velocity decreases at the bank of the river near the bank.

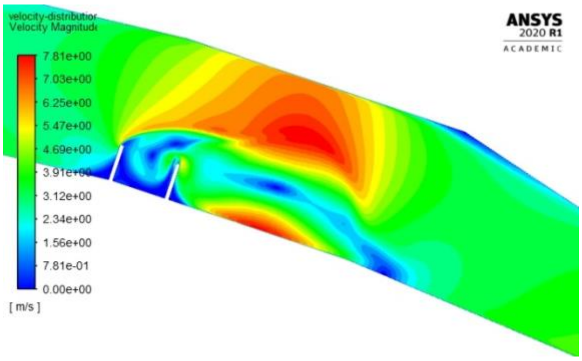

Figure 9 Double barbs (20mx2m, 90° upstream)

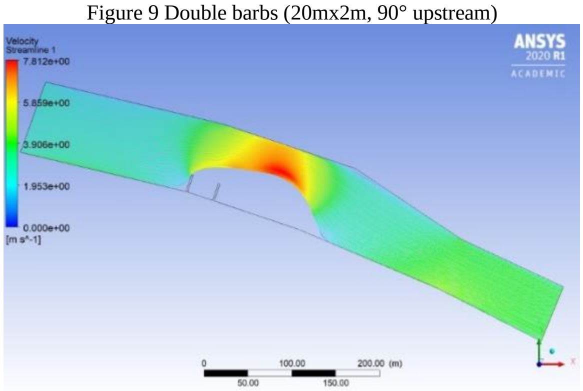

Figure 10 Streamline Double barbs (20mx2m, 90° upstream)

In another case as shown in Figure 11 and Figure 12 with single barb (20mx2m, at 30° upstream) at B-B and C-C shows increase in flow velocity upto a maximum of 10.3 m/s, downstream of the second barb away from its toe. Also there is a pattern of increase of flow velocity along the bank of the river downstream of each barb which is not desirable. The velocity streamline shows that the flow is absent in the areas where the velocity magnitude shows increase in the flow velocity along the bank downstream of the barbs.

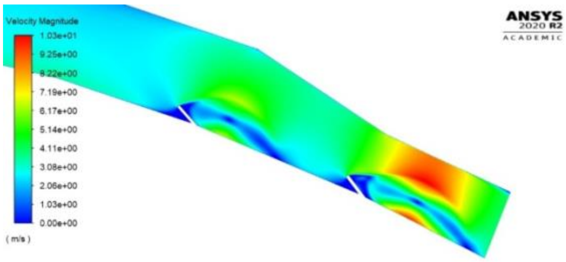

Figure 11 Single barb (20mx2m, 30° upstream)

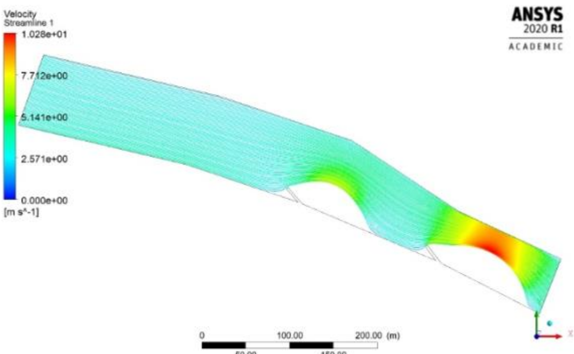

Figure 12 Streamline Single barb (20mx2m, 30° upstream)

The flow velocity magnitude and streamline of velocity in case with double barbs (20mx2m, 30° upstream) at spacing of 30m in between at B-B and C-C are shown in Figure 13 and Figure 14. The velocity magnitude shows that the velocity increases up to 10.27 m/s, downstream away from the toe of the barbs structure at section C-C. The flow velocity around the bank of the river around barbs structure substantially reduces to zero but just downstream of second barb at each location the velocity increases significantly.

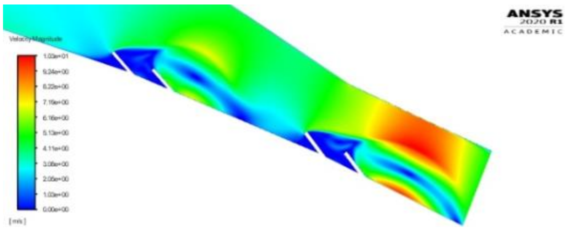

Figure 13 Double barbs (20mx2m, 30° upstream)

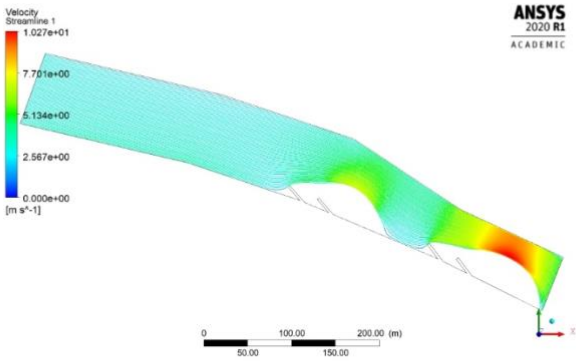

Figure 14 Streamline Double barbs (20mx2m, 30° upstream)

The flow velocity magnitude and streamline of velocity in case with single barbs (20m x 2m, 90°upstream) at B-B, C-C as shown in Figure 15 and Figure 16 respectively shows that the velocity increases up to 13.94 m/s downstream along the toe of the barbs structure at section C-C and the flow velocity at the bank of the river around barbs structure substantially reduce to zero. The velocity magnitude shows that there is increase in flow velocity along the bank of the river downstream of each barb location.

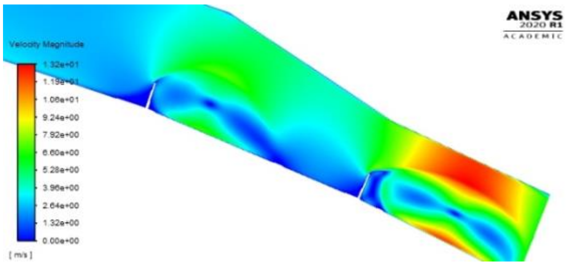

Figure 15 Single barbs (20m x 2m, 90°upstream)

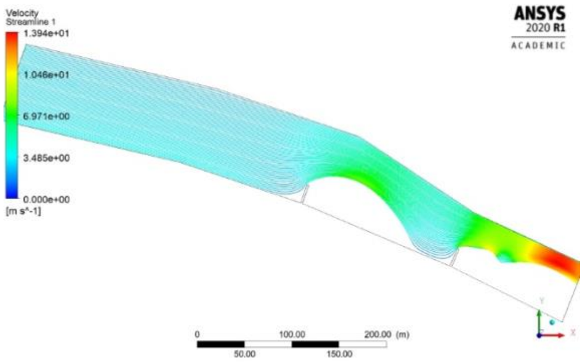

Figure 16 Streamline Single barb (20m x 2m, 90° upstream)

The flow velocity magnitude and streamline of velocity in case with double barbs (20mx2m, 90° upstream) at spacing of 30m in between at B-B and C-C as shown in Figure 17 and Figure 18. The velocity magnitude shows that the velocity increases up to 11.12 m/s at the bank away from the highway. The flow velocity around the bank of the river around barbs structure substantially reduces to zero but just downstream of second barb at B-B location the velocity increases significantly.

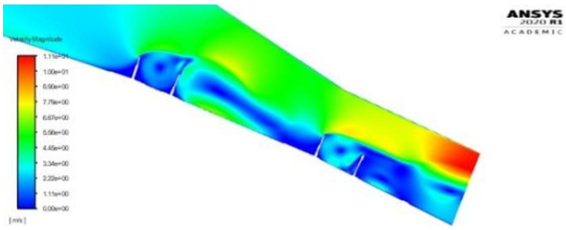

Figure 17 Double barbs (20m x 2m, 90° upstream)

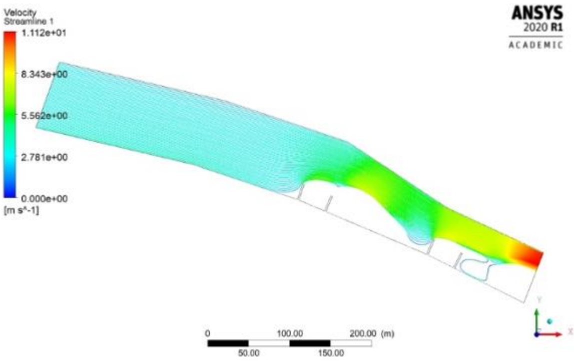

Figure 18 Streamline Double barbs (20m x 2m, 90° upstream)

B. Conclusion

A comparison of velocity magnitude and velocity streamline was done among all different cases considered for this project in turns. In the case without any barb structure the flow velocity along the bank of the river near section A-A is approximately 3.5m/s while in other cases with barbs structure the velocity in the same region is reduced near to 0 m/s. Among various cases the one with double barbs at an angle of 90° in section B-B and C-C (Figure 4.17, Figure 4.18) shows significant reduction in flow velocity near the river bank along the highway. In conclusion, the simulation results show that, the construction of double barbs at sections B-B and C-C at an angle of 90° to the upstream confine the flow towards the centre of the river and thereby induce bank stability effectively.

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References

[1] M. Hossain, S. Abdullah Al, L. Wang, M. J. Uddin andA. Ahsan (2016). Placement of stream barb encouraged river channel flow towards bank stability. Journal of Advanced Civil Engineering Practice and Research. 3. 15-22.

[2] J. Fox, L. Kjos andT. Papanicolaou. (2002). Anenvironmentally friendly barb design for Washington state. Research & Extension Regional Water Quality Conference 2002 February 20- 21, Vancouver, WA.

[3] M. Hossain, S. Abdullah Al,A.K.M. Adham, M. J. Uddin and M. Chowdhury (2014). Effects of barb installation on riverbank stability: A numerical simulation. Journal of Agricultural Engineering, the Institute of Engineer Bangladesh. 41/AE.

[4] D. Acharya, K. Basnet, K.P. Bhandari, and B.B. Sadadev. (2020) Floodplain mapping of ungauged Seti river in Pokhara, Nepal using HEC-RAS

[5] E. Mohamed & T. Papanicolaou. (2016). Design procedure enhanced with numerical modeling to mitigate river-bank erosion. MATEC Web of Conferences. 68. 08003. 10.1051/matecconf/20166808003.

[6] Basnet, K., and D. Acharya. "Flood Analysis at Ramghat, Pokhara, Nepal Using HEC-RAS". Technical Journal, Vol. 1, no. 1, July 2019, pp. 41-53, doi:10.3126/tj.v1i1.27591. Eason,